Geophysics using Hyper-K

Akimichi Taketa
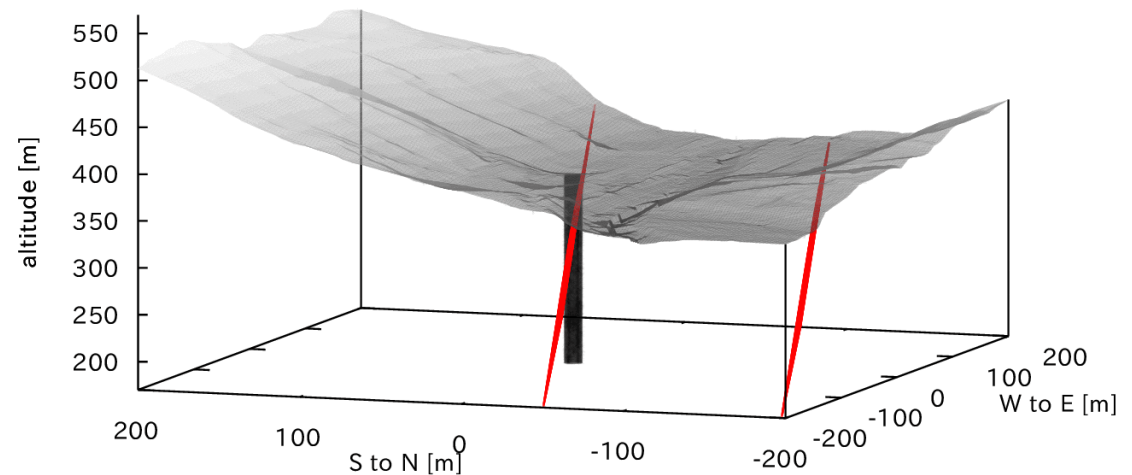Earthquake Research Institute, University of Tokyo

Recent progress of muography
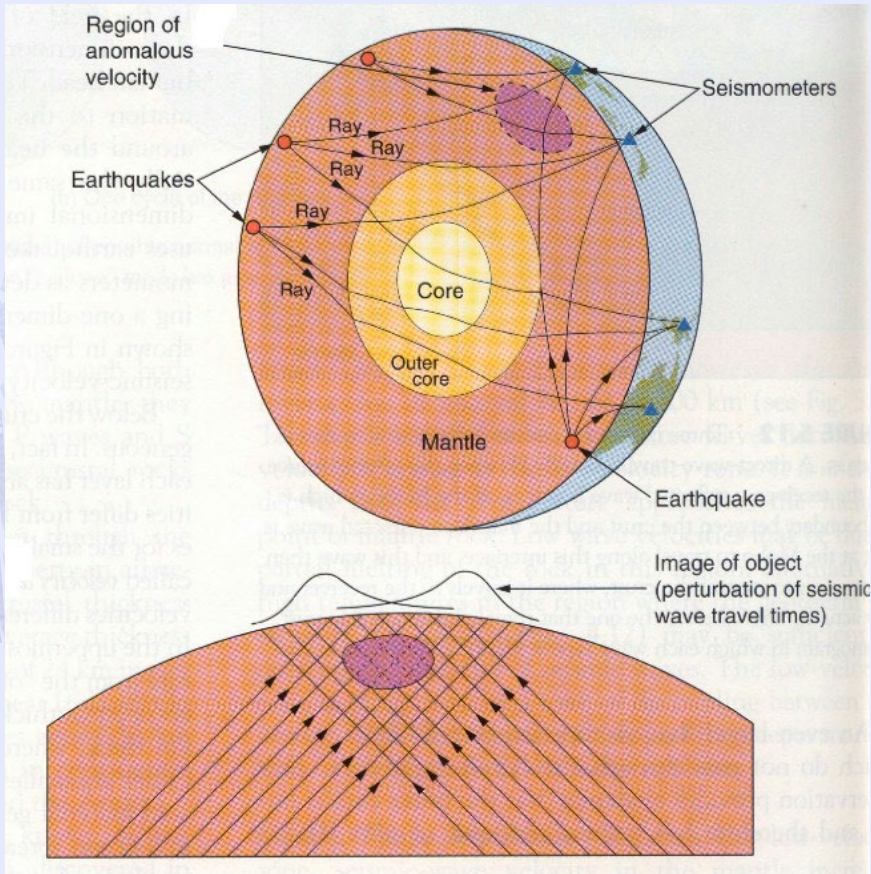
伊豆大室山
Omuro-yama

跡津川断層
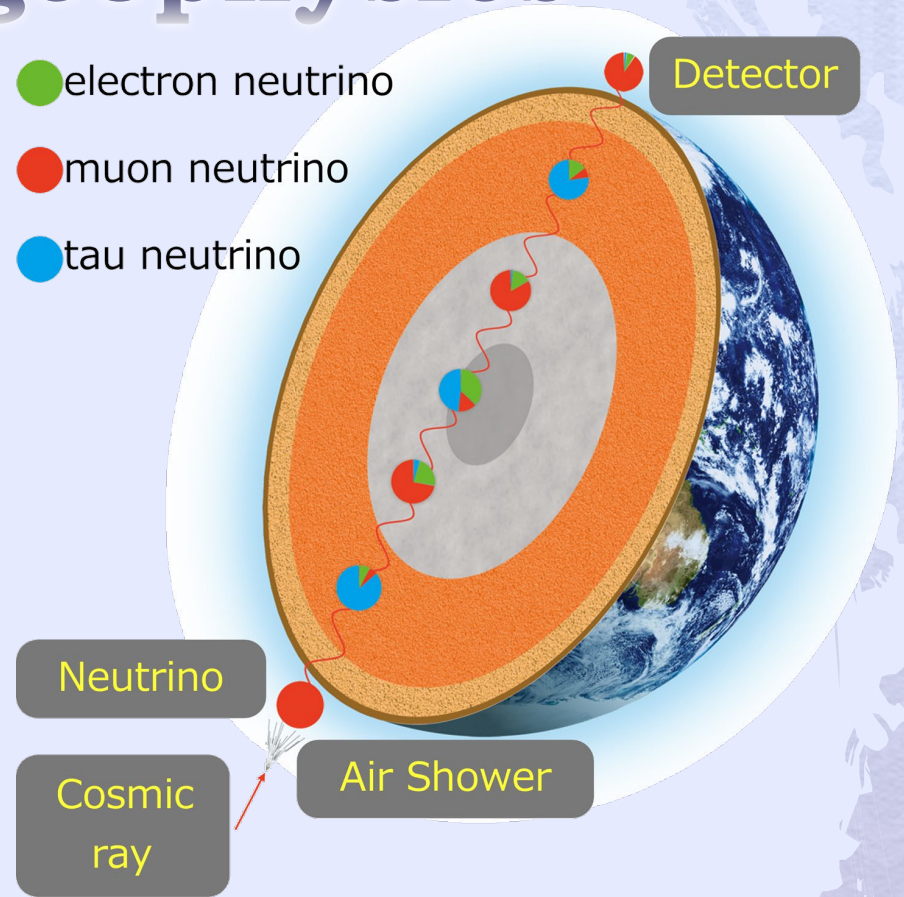Atotugawa-fault

https://www.er...
tokyo.ac.jp/CH...
data/omuro3ds...

Multimessenger geophysics

Matter density by seismic tomography

- electron neutrino
- muon neutrino
- tau neutrino

Detector

Neutrino

Cosmic ray

Air Shower

Electron density by neutrino oscillation tomography

The ratio of electron density to matter density is equal to the ratio of the atomic number to mass number(Z/A)
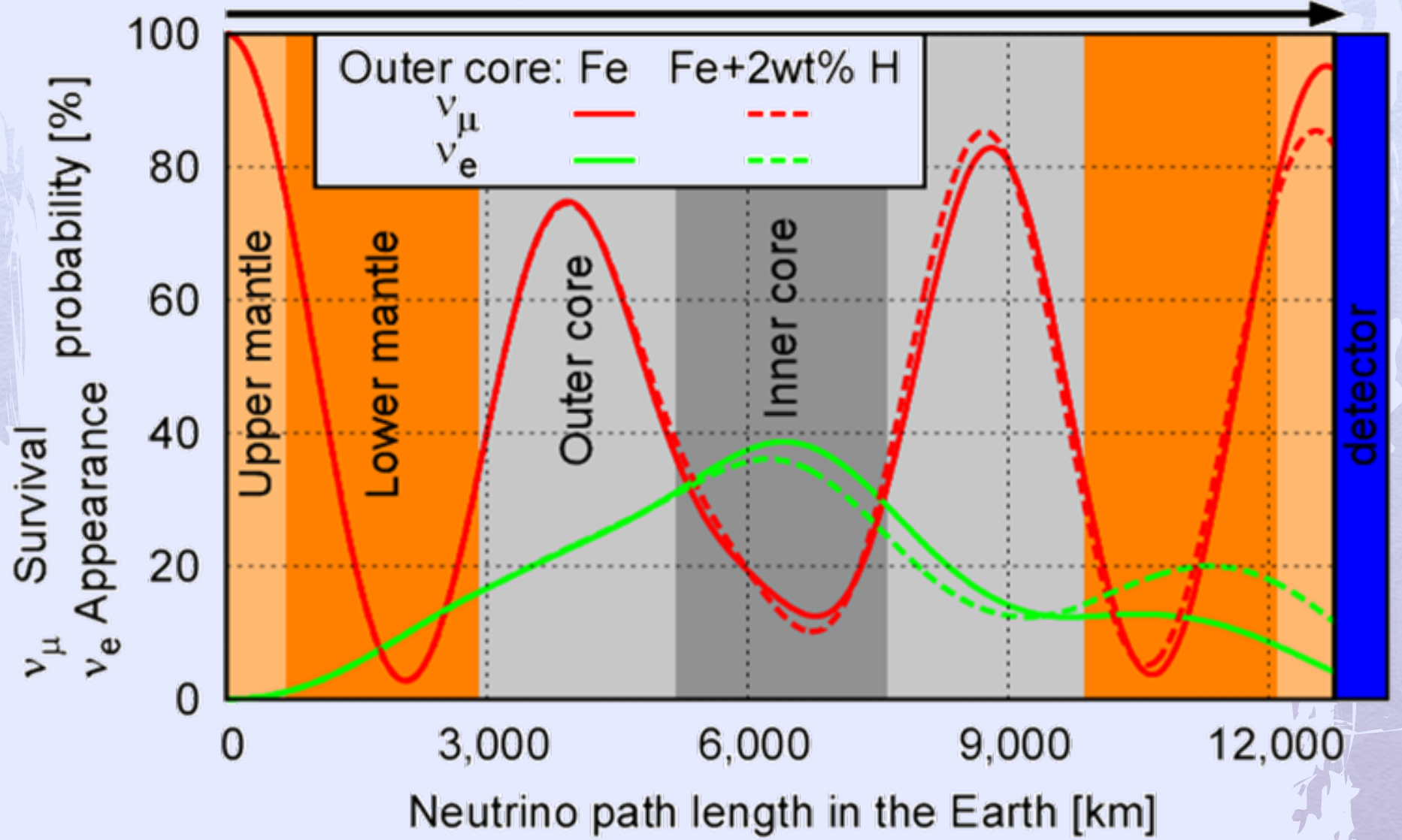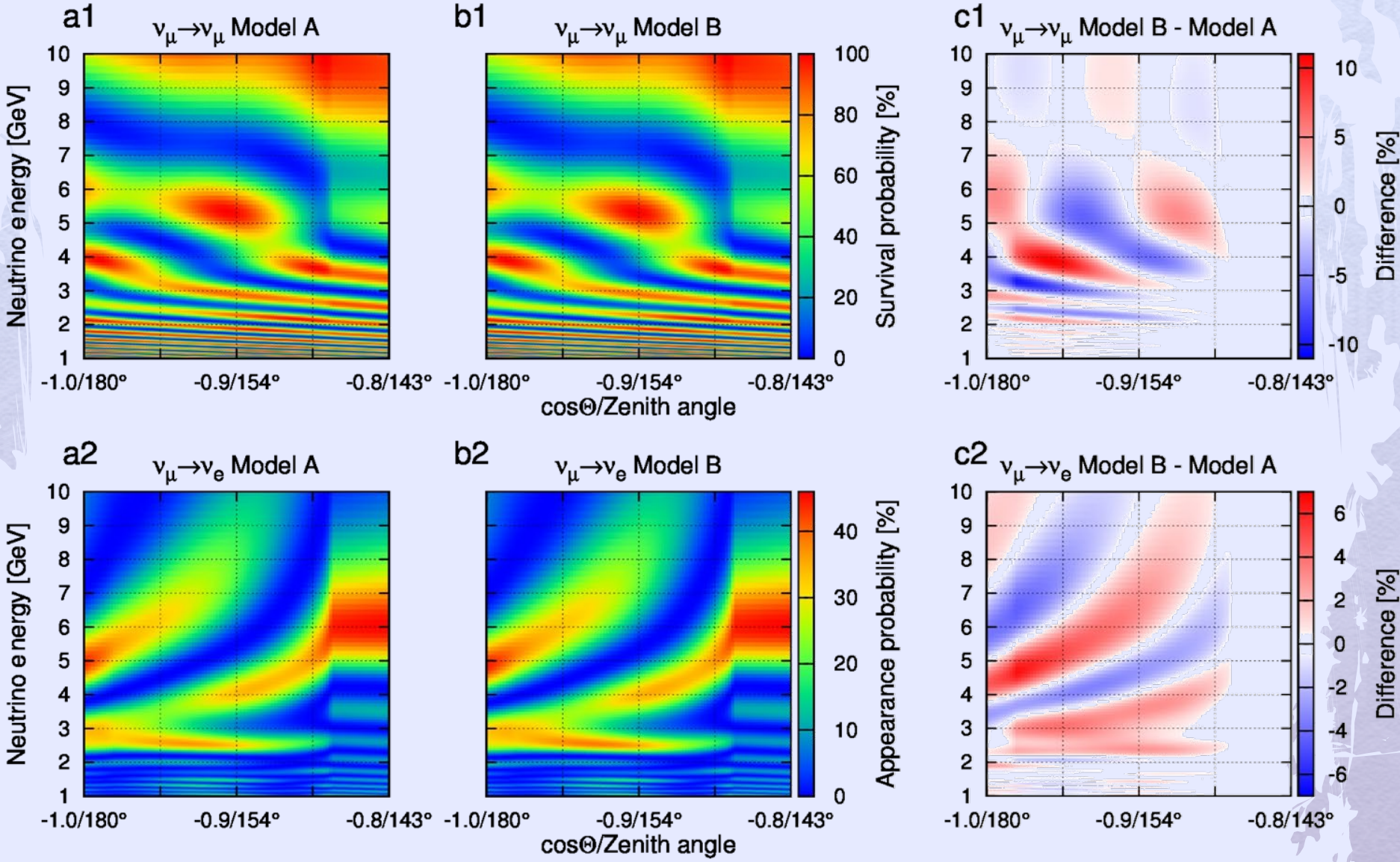Core composition "measurement"

Neutrino oscillation in the Earth

ν_μ 4 GeV $180°/\cos\Theta = -1.0$

Oscillograms (Fe vs Fe+2wt%H)

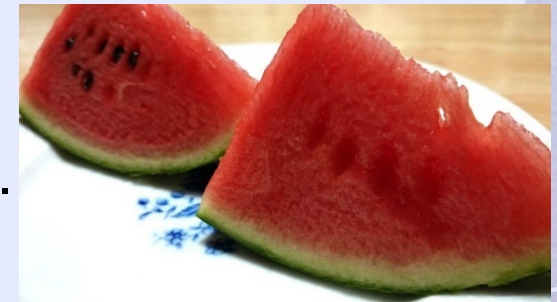# Other geophysics cases

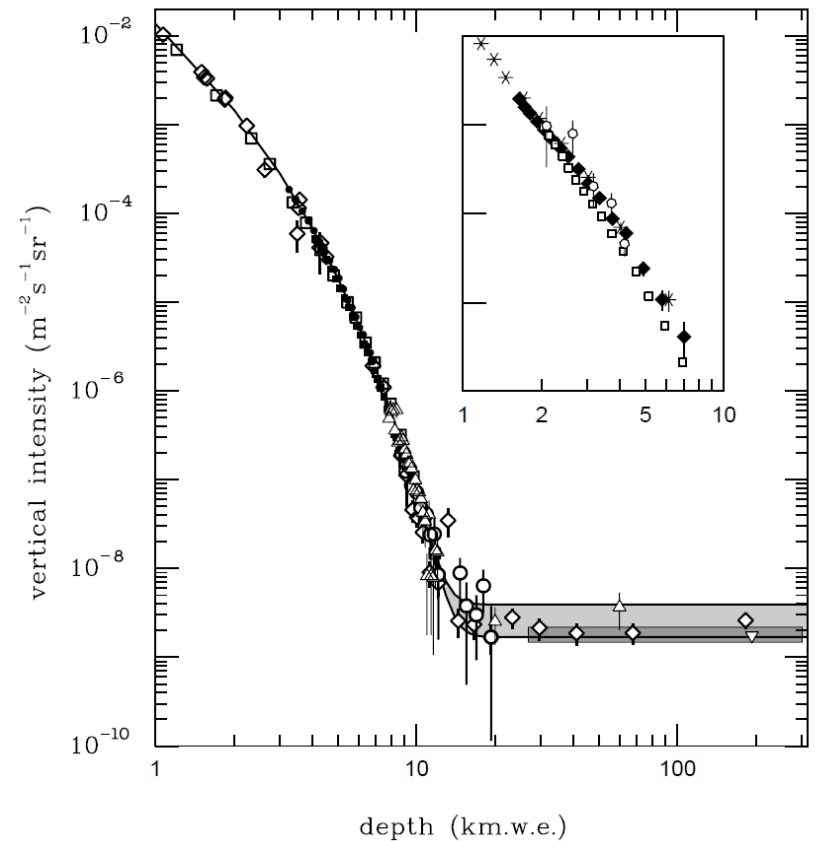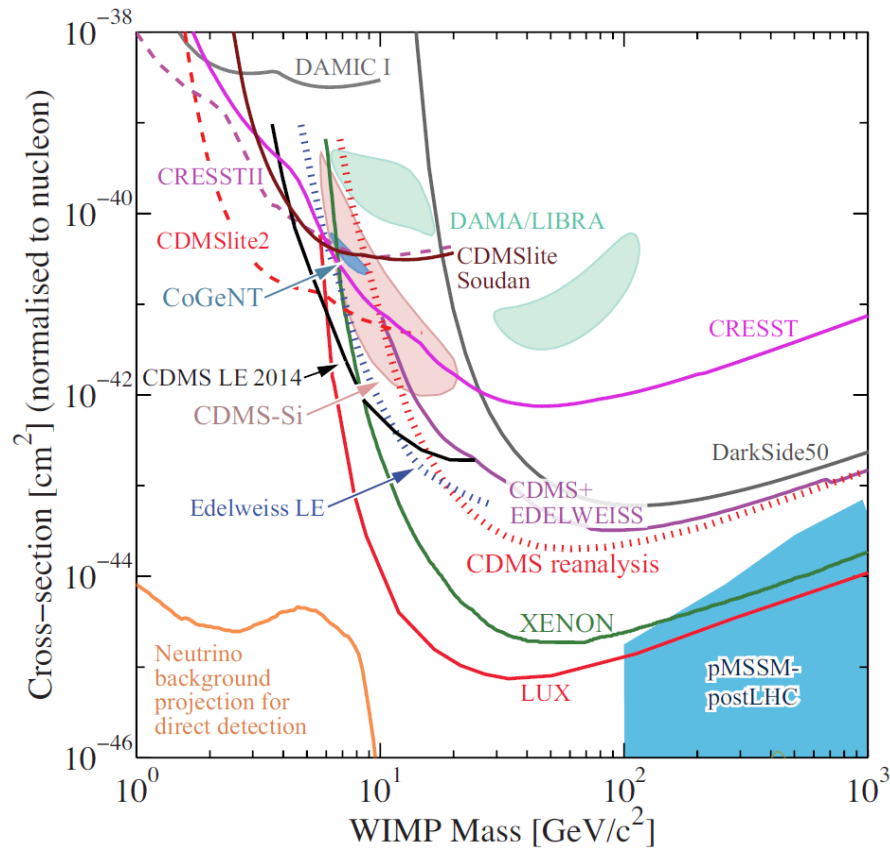Hydrophilic
Hydrophobic

- Density gradient of OC
- Composition of OC must be homogeneous.

- Composition/density difference of the mantle
- East/West hemi.
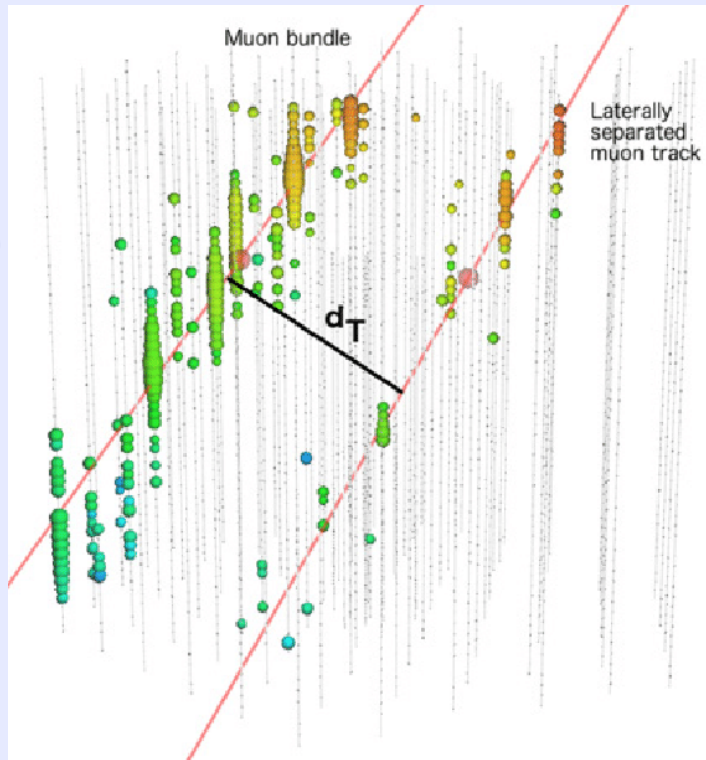- Water/Land hemi.
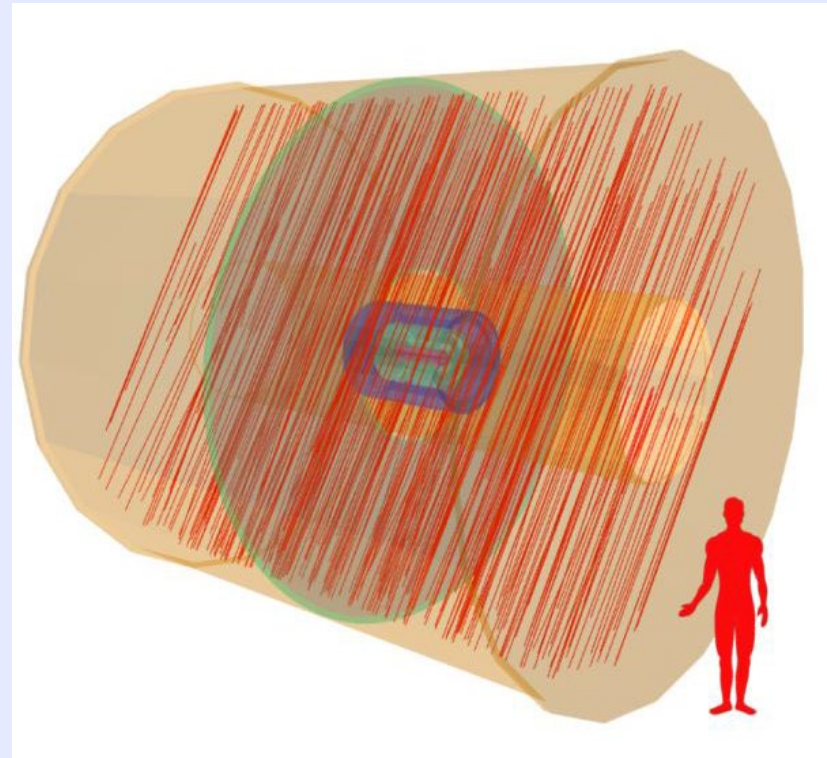
- Is mantle homogeneous ?

Neutrino floor of muography

Maximum thickness of muography is ~4km

Limited by neutrino "background"...

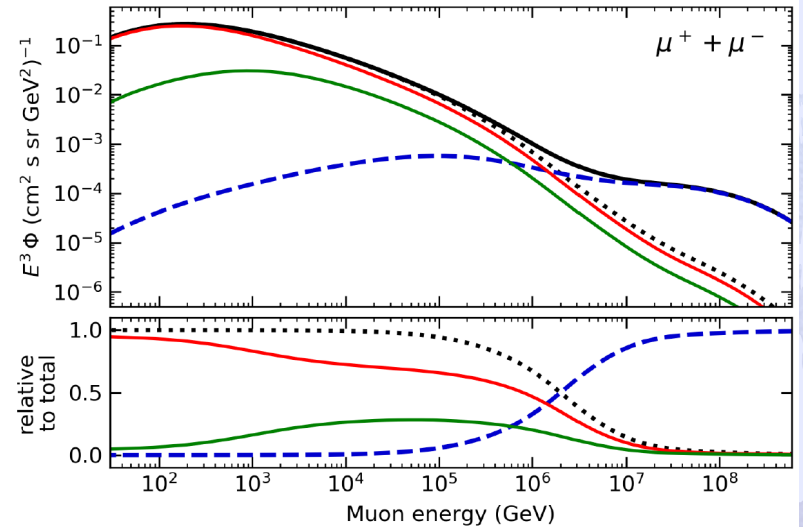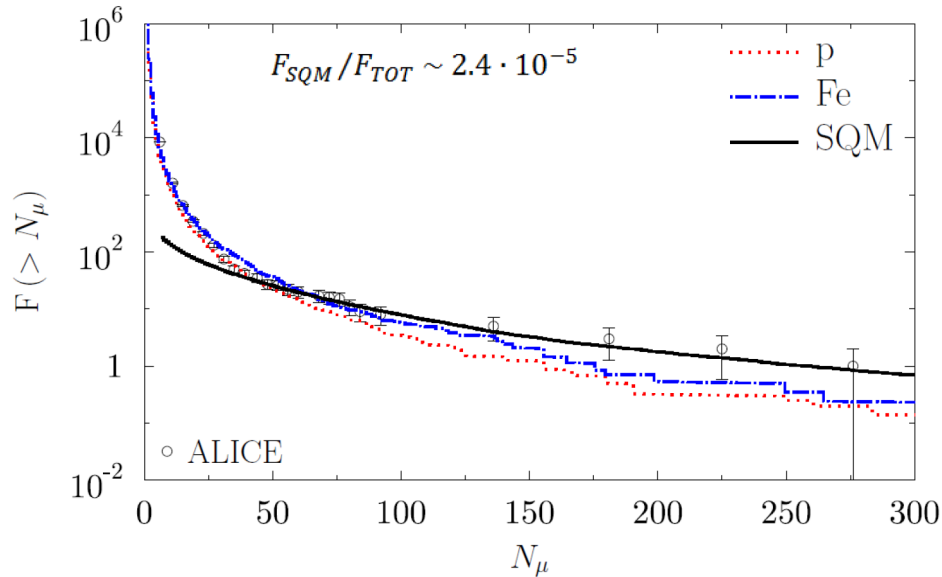# Coincident muons (muon bundle)
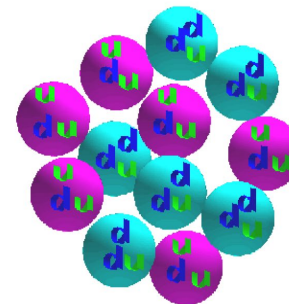
IceCube

LHC ALICE

To reduce the noise, take coincidence. But..

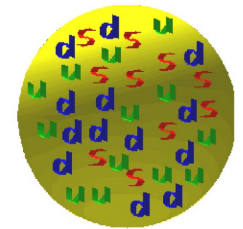# Muon excess problem etc...

We need them for muography
- ◆ Energy spectrum
- ◆ Angular distribution
- ◆ Multiplicity + topology(Pt)

Nucleus (^{12}C)
Z=6, A=12
Z/A = 0.5

Strangelet*
A=12 (36 quarks)
Z/A = 0.083

Use HK !

Hyper-Kamiokande

Super-K

41.4m

25yah

40m

1,156m a.s.l
二十五山
(海抜1,156m)
霧天雄

0M=845m a.s.l.

overburden
648m

Hyper-K

300M
370M
430M

508m a.s.l

HK MC

muon flux [cm^{-2} s^{-1} sr^{-1}]

$\times 10^{-7}$

0 50 100 150 200 250 300 350
N   W   S   [deg]

Muon bundle Anisotoropy by Alice
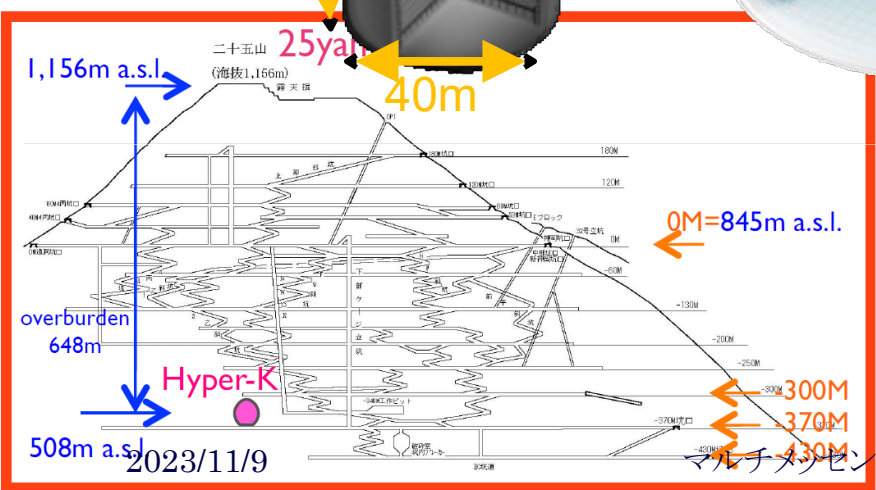
NEUTRINO OSCILLATION

COMPOSITION OF THE EARTH

EVOLUTION OF THE EARTH

GOOD PHOTO-SENSOR

COLLABORATION
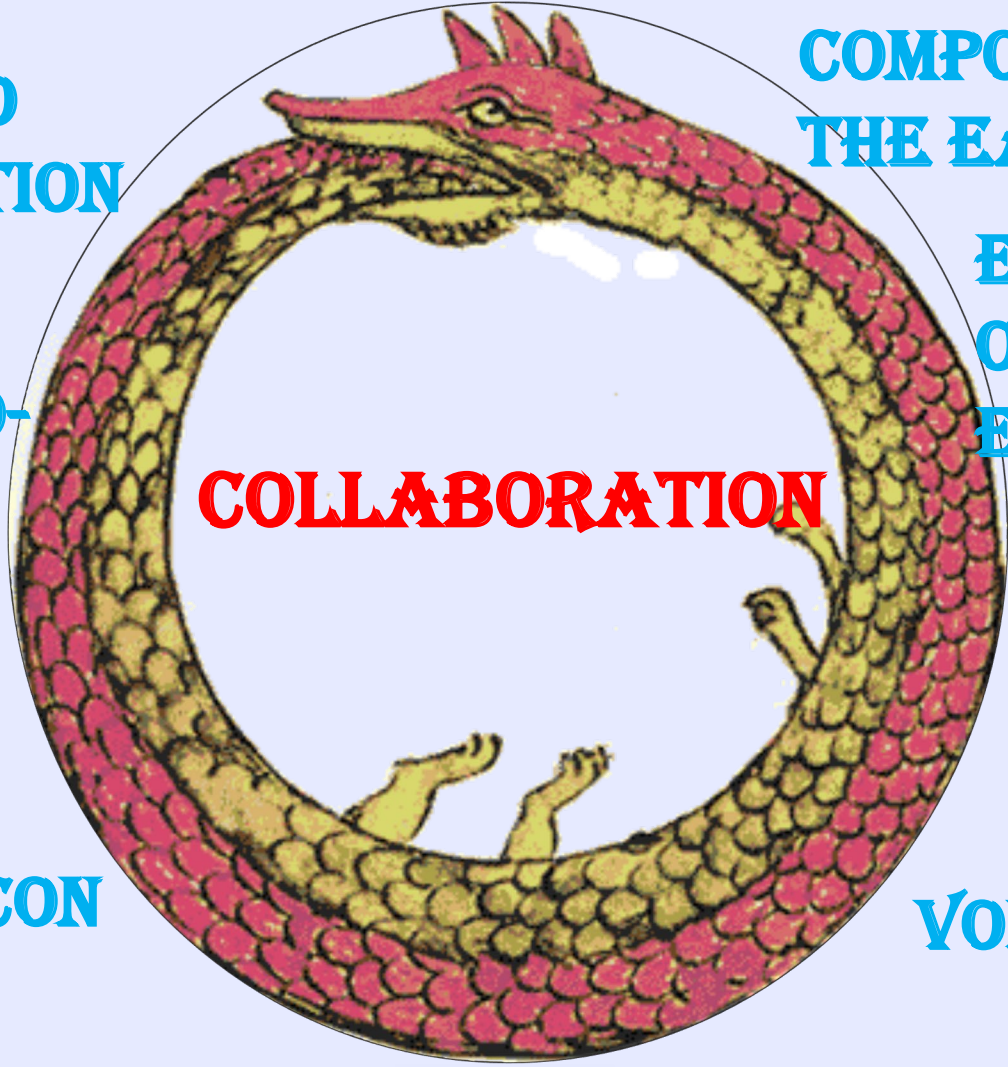
GLASS QUALITY

MANTLE DYNAMICS

SILICA/ZILCON SAND

VOLCANOLOGY

What can we do using next generation detector using atm neutrino ?

- Z/A ratio of materials
  - Fe :0.466, Light material :~0.5, Hydrogen :**1**
  - **More sensitive to Hydrogen**
- Matter density profile : modified PREM
- atm neutrino flux : Honda flux 2011
- Mantle is pyrolite (Z/A=0.496)
- Inner Core is Pure Iron (Z/A=0.467)
- **Z/A of outer core : free parameter**
- **Normal hierarchy, three generation**
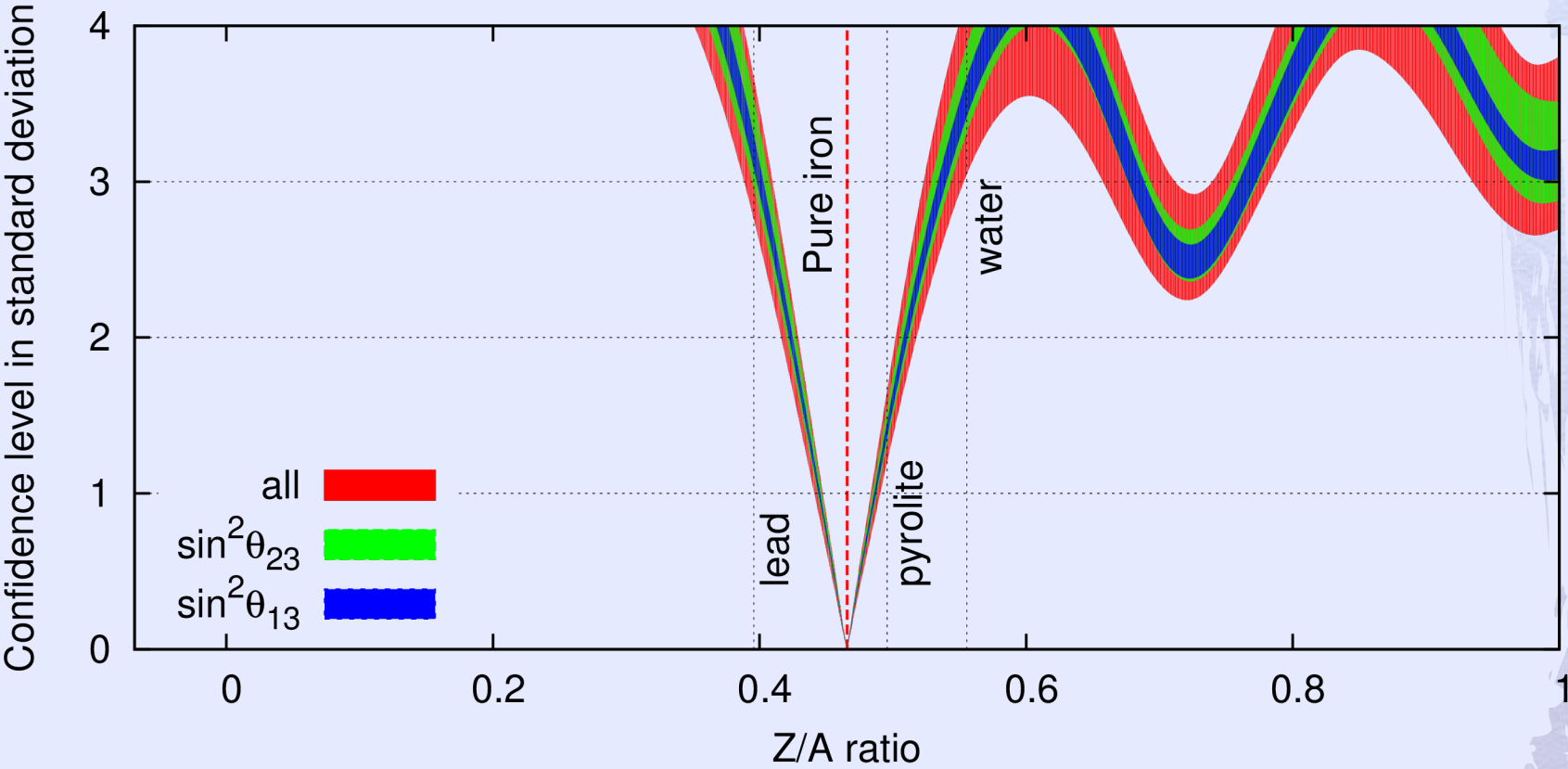- Oscillation parameter : Capozzi et al. 2014

$$\sin^2\theta_{12} = 0.308^{+0.017}_{-0.017} \qquad \delta_{CP} = 1.39^{+0.38}_{-0.27} \times \pi$$

$$\sin^2\theta_{13} = 0.0234^{+0.0020}_{-0.0019} \qquad \Delta m^2_{21} = (7.54^{+0.26}_{-0.22}) \times 10^{-5}$$
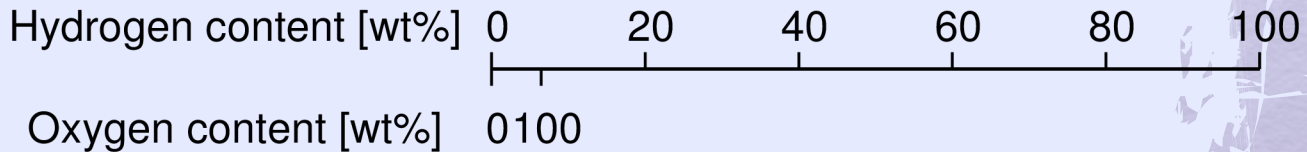
$$\sin^2\theta_{23} = 0.437^{+0.033}_{-0.023} \qquad \Delta m^2_{32} = (2.39^{+0.06}_{-0.06}) \times 10^{-3}$$
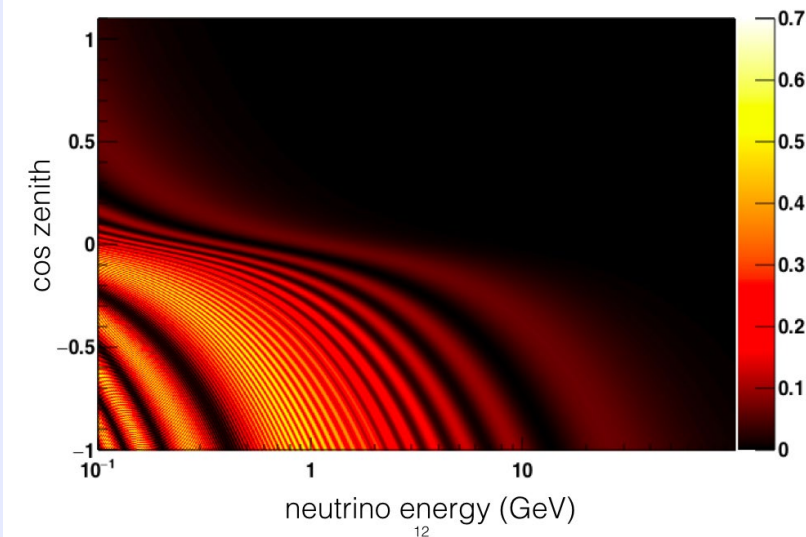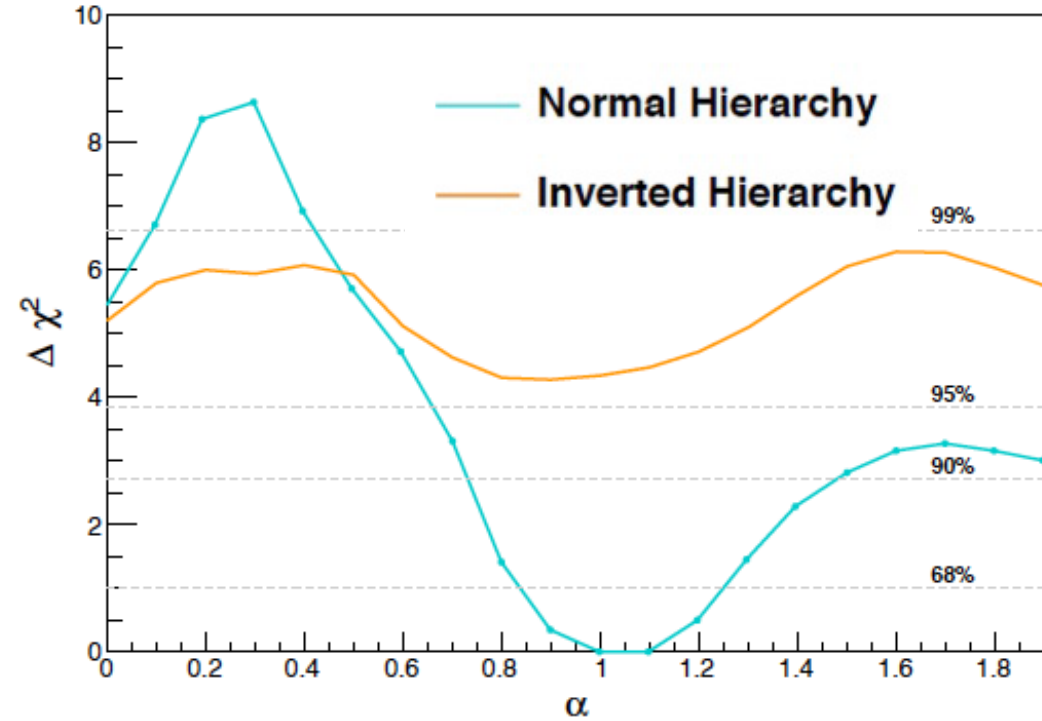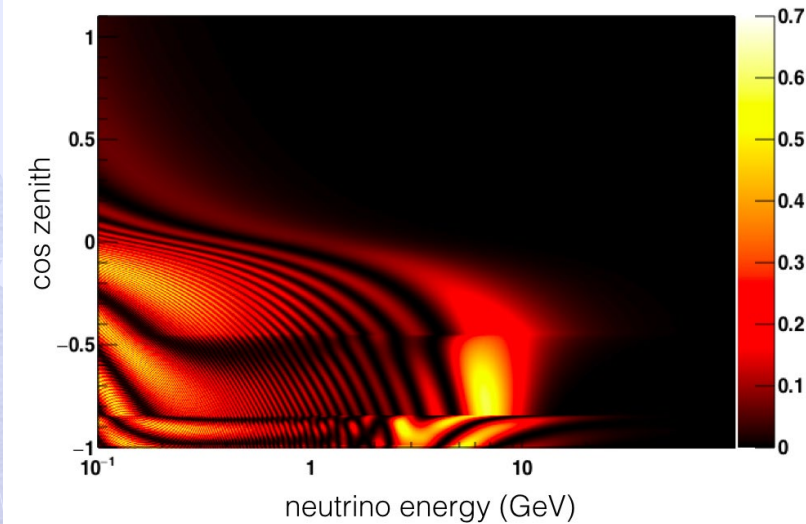
Outer Core composition by HK

10Mtyr

Legend: all (red), $\sin^2\theta_{23}$ (green), $\sin^2\theta_{13}$ (blue)

Y-axis: Confidence level in standard deviation
X-axis: Z/A ratio

Labels in plot: Pure iron, water, lead, pyrolite

$\Delta E, \Delta\Theta$:
eq. to HK

Hydrogen content [wt%]   0   20   40   60   80   100
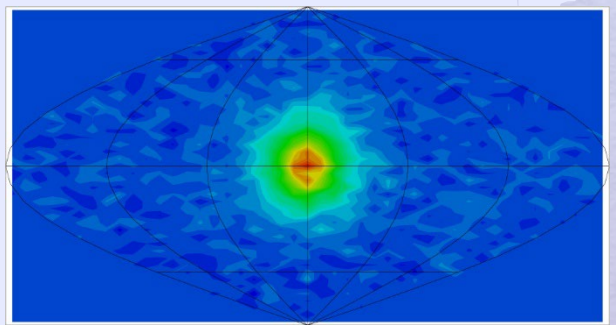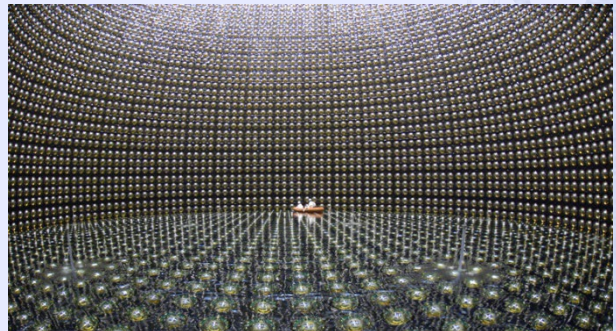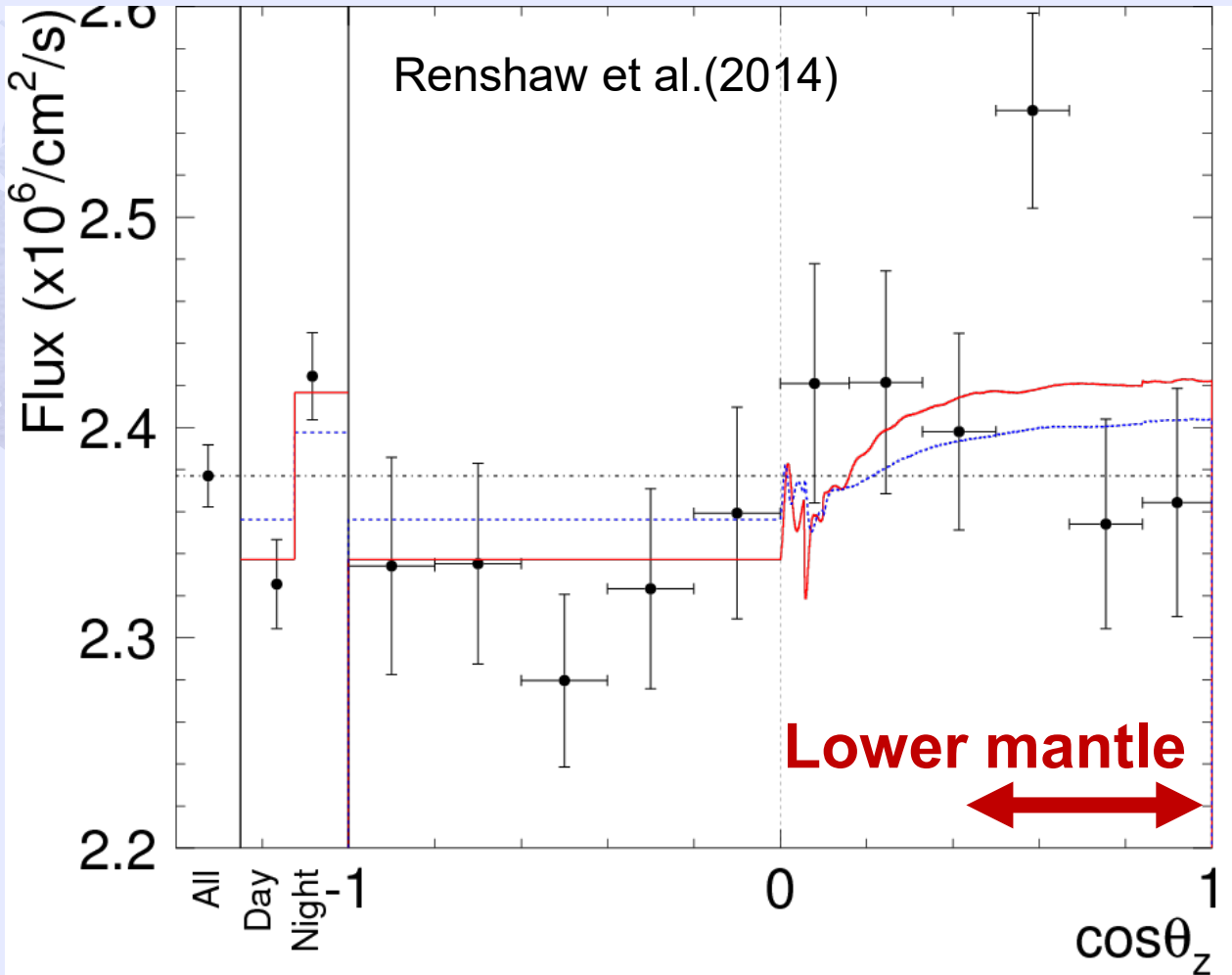
Oxygen content [wt%]   0100

MSW effect measured by SK atm

- ◆ Inside of the Earth is not vacuum !
- ◆ 2.3σ w/o sys, 1.6σ w sys

Rediscovery of the Earth by neutrino oscillation

◆ Already done by SK (solar ν)

   ◆ Average electron density of entire earth < 30% resolution

Renshaw et al.(2014)

Lower mantle

Neutrino absorption measured by IC